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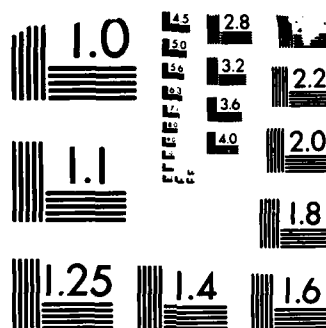UNCLASSIFIED   N00014-83-K-0423   F/G 11/9   NL

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
2	AD A137988	

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
PROPERTIES OF POLYURETHANE ANIONOMERS: IONIZATION VIA BIMOLECULAR NUCLEOPHILIC DISPLACEMENT OF THE URETHANE HYDROGEN	Interim Technical Report
	6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
K. K. S. Hwang, T. A. Speckhard and S. L. Cooper	N00014-83-K-0423

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Department of Chemical Engineering University of Wisconsin Madison, WI 53706	--

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Department of the Navy Office of Naval Research Arlington, Virginia 22217	February 1, 1984
	13. NUMBER OF PAGES
	32

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	Unclassified
	15a. DECLASSIFICATION. DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

To be published in Journal of Macromolecular Science-Physics

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Polyurethane, anionomer, structure-property study, block copolymer

galina

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two series of polyether polyurethane anionomers based on 4,4' diphenylmethane diisocyanate (MDI) and polytetramethylene oxide (PTMO) were synthesized and their properties investigated. Ionization proceeded via a bimolecular nucleophilic displacement reaction with sodium hydride followed by a ring opening reaction with γ-propane sultone. The lower hard segment content (20 wt% MDI) control material exhibited an initial one phase morphology that underwent phase separation upon ionization with subsequent development of hard segment ordering. These changes in morphology were accompanied by dramatic improvements in

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20. Abstract (cont.)

mechanical properties. The 38 wt% MDI control material possessed a two
phase morphology and well developed hard segment ordering. Ionization
disrupted the hard segment ordering and at low levels decreased the degree
of phase separation. Further ionization led to reattainment of the original
degree of phase separation and a marked improvement in mechanical strength.
The differences in properties of the two series of materials are discussed
and compared with properties of other polyurethane ionomers reported in the
literature.

OFFICE OF NAVAL RESEARCH

Contract N00014-83-K-0423

TECHNICAL REPORT NO. 2

Properties of Polyurethane Anionomers:
Ionization via Bimolecular Nucleophilic
Displacement fo the Urethane Hydrogen

by

K. K. S. Hwang, T. A. Speckhard, and S. L. Cooper

Prepared for Publication

in the

Journal of Macromolecular Science-Physics

Department of Chemical Engineering
University of Wisconsin
Madison, Wisconsin 53706

February 1, 1984

Accession For		
NTIS GRA&I		☒
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INTRODUCTION

The incorporation of ionic functionality into the hard sgement units of polyurethane block copolymers produces materials known as polyurethane ionomers which possess improved mechanical properties (1-6). The improvement of properties has been attributed to changes in morphology and microstructure upon ionization. Ionization increases the polarity difference between the hard and soft segments and thus has been found to improve the degree of phase separation. Ionization also improves hard segment domain cohesion through coulombic interactions of the ionic groups. Both of these effects enhance the ability of the hard segment domains to act as a filler and a physical crosslink thereby increasing the strength of the material. For a more thorough introduction to this subject the reader is referred to the introduction in the preceeding paper.

In previous studies of polyurethane ionomers (1-6), data has been presented on materials that incorporate N-methyl diethanolamine (MDEA) as the hard segment chain extender. Ionization proceeds by quarternization of the tertiary amine of MDEA followed by reaction in solution with γ-propane sultone. A ring opening reaction occurs on the sultone resulting in the formation of a quarternary ammonium ion closely linked to a sulfonyl anion. The material produced is termed a zwitterionomer (1,6). The zwitterionomer can be further reacted to produce materials known as cationomers or anionomers. Anionomers are produced via reaction of the zwitterionomer with a metal acetate producing a metal-sulfonyl ion pair with reduction of the ammonium ion to the tertiary amine by generation of methyl acetate (3). In this case the charge on the polymer backbone is negative and thus the material is termed an anionomer. A positively charged polymer backbone results when the MDEA extended polyurethane is reacted wtih an alkyl halide to produce a quarternary ammonium halide pair - a cationomer. The limitation of these synthetic schemes is that the hard segment chain extender must contain a tertiary amine group.

An alternate method of producing polyurethane anionomers involves the bimolecular nucleophilic displacement reaction of the urethane hydrogen (4,5). The advantage of this method is that it is not dependent on the choice of chain extender and can thus be carried out on a wide variety of polyurethane block copolymers. Another difference compared with the method based on MDEA is that the potential maximum ionic content is higher since there are more ionization sites per hard segment unit. For example, in a 3/2/1 molar ratio diisocyanate/MDEA/soft segment material there are three urethane hydrogens for every tertiary amine group. The basic synthetic procedure is shown in scheme 1. The urethane nitrogen is first reduced by reaction with sodium hydride in N,N-dimethylformamide (DMF) solution producing hydrogen gas. The nitrogen anion is then reacted with γ-propane sultone which undergoes a ring opening reaction to produce the polyurethane anionomer.

Using the method outlined above, two series of polyether polyurethane anionomers were prepared (Table 1) from conventional polyether polyurethanes PTMO-20 (ET-20) and PTMO-38 (ET-38). PTMO-20 is a 1:1 copolymer of 4,4' diphenylmethane diisocyanate (MDI) and polytetramethylene oxide (PTMO) (number average molecular weight of 1000) exhibiting a one phase morphology (1). This polymer contains 20 wt% MDI. It should be noted that recent work has apparently shown that PTMO-20 (ET-20) can with aging develop a phase separated morphology (7,8). PTMO-38 is synthesized from a 3/2/1 molar ratio of MDI/butane diol (BD)/PTMO (1000). PTMO-38 contains 38 wt% MDI and possesses a phase separated morphology (9). Each of these polymers was subsequently ionized to several different levels (Table 1). The nomenclature used in Table 1, for example PTMO-20-4.5, describes the soft segment type (PTMO), weight percent MDI (20), and the weight percent $NaSO_3$ (4.5).

The purpose of this investigation was to study the effects of ion incor-

poration and ionization level on the morphology and properties of PTMO based polyurethane block copolymers. The polyether polyurethane anionomers described above were investigated using differential scanning calorimetry (DSC), infrared spectroscopy (IR), dynamic mechanical analysis and stress-strain testing techniques. The results of.this study are compared with results on other anionomers (3) and zwitterionomers (1) that were synthesized from polyurethanes containing MDI, 1000 molecular weight PTMO and MDEA.

<div align="center">EXPERIMENTAL</div>

Materials

4,4' diphenylmethane diisocyanate (MDI, Eastman Kodak Chemical Co.) and γ-propane sultone (Aldrich Chemical Co.) were vacuum distilled. Polytetramethylene oxide (PTMO, Quaker Oats Co.) was dehydrated under vacuum at 50°C for two days. 1,4 butane diol (BD, Aldrich) was dehydrated over calcium hydride for two days and then vacuum distilled. N,N-dimethyl formamide (DMF, Aldrich) was degassed for 48 hours. Sodium hydride (NaH, Aldrich) and stannous octoate (M&T Chemicals) were used as received.

Synthesis

1. Polyurethane Block Copolymers

PTMO based polyurethane block copolymers were synthesized by a bulk condensation polymerization technique in a nitrogen atmosphere. PTMO-20, the MDI/PTMO copolymer, was prepared by mixing PTMO and molten MDI in a one to one molar ratio along with .15 wt% stannous octoate catalyst. To ensure complete reaction the mixture was kept at 100°C for ten hours. PTMO-38 was prepared by the conventional two step melt polymerization procedure (10). A three to one molar ratio of MDI and PTMO and .15 wt% catalyst was first mixed to generate the MDI tipped PTMO oligomers. Chain extension was accomplished by adding the appropriate amount of BD to produce an overall 3/2/1 molar ratio of MDI/BD/PTMO. To ensure that the reaction was complete the reaction mixture was kept at 100°C

for ten hours.

2. Polyurethane Anionomers

Polyurethane anionomers were synthesized according to scheme 1. The polyurethane block copolymer was dissolved in DMF (5 % wt/vol) and mixed with a dispersion of NaH in DMF. The reaction mixture was kept at -5 to 0°C under nitrogen and vigorously stirred. Within approximately seven minutes a greenish-yellow color appeared. After stirring for 15 minutes an equivalent amount (compared with NaH) of γ-propane sultone was added and the mixture was kept at 50°C for 1 hour. The nitrogen substitution reaction was confirmed by infrared spectroscopy and nuclear magnetic resonance experiments. No observable change in molecular weight of the polyurethane ($\bar{M}_w$ = 60,000 using a polystyrene calibration scale) due to the NaH reaction was observed in gel permeation chromatography experiments using the method described by Adibi et al (11). Adibi et al. used methyl iodide to methylize the sodium substituted polyurethane and found that the molecular weight of the methylized polyurethane was the same as the molecular weight of the original material provided that the NaH reaction was carried out at 0°C.

The reaction solution was filtered and precipitated into toluene. The precipitated anionomer was further washed with refluxing methanol in a soxhlet extractor for at least three days to remove any residual γ-propane sultone and NaH. Elemental analysis for sodium indicated that the NaH reacted completely. Finally, the materials were dried under vacuum at 50°C for one week. It should be noted that the higher ionic content samples tended to absorb water upon exposure to atmosphere. In fact higher ionic content PTMO-38 based materials than those shown in Table 1 were prepared but these materials absorbed significant amounts of water upon exposure to the atmosphere and became quite soft. Also, after exposure to the atmosphere these highly ionized materials were insoluble in N,N-dimethyl acetamide (DMA) unlike the materials listed in Table 1.

-4-

Samples for mechanical and thermal testing were prepared by compression molding at 180°C for three minutes followed by slow cooling to room temperature. The cooling process took approximately four hours. Samples for infrared spectroscopy experiments were prepared by spin casting from dilute DMA solutions.

Characterization

Differential scanning calorimetry (DSC) thermograms were recorded from -150 to 230°C using a Perkin-Elmer DSC 2 equipped with a date processing unit. The heating rate was 20°C/minute and the quenching rate was 320°C/minute. The data processing unit allowed automatic subtraction of the background and normalization of the thermograms for sample weight.

Dynamic mechanical data were obtained using a microprocessor controlled Rheovibron DDV-II. Samples were cooled to -150°C and data were taken at a test frequency of 110 Hz and a temperature rise rate of 1°C/minute.

Room temperature uniaxial stress-strain data were taken on an Instron table model tensile testing device at a crosshead speed of .5 in/min. Samples were prepared using an ASTM D412-D standard die.

Infrared survey spectra were recorded using a Perkin-Elmer 180 double beam spectrophotometer.

RESULTS AND DISCUSSION

Infared Spectroscopy

Figure 1 shows IR survey spectra for both polyether polyurethane control materials and two of the corresponding high ionic content anionomers. In both control polymers the NH band in the region of 3200-3500 cm^{-1} appears almost completely hydrogen bonded since the NH bonded peak at 3310 cm^{-1} predominates while the free (non-hydrogen bonded) NH peak at 3460 cm^{-1} is barely detectable. However the carbonyl band in the region of 1650-1750 cm^{-1} is significantly dif-

-5-

ferent in the two control materials. For PTMO-20 the carbonyl absorption is predominantly found at 1730 cm^{-1} representing non-bonded carbonyl groups with a shoulder at 1700 cm^{-1} due to hydrogen bonded carbonyls. Since the NH group is mostly hydrogen bonded while the carbonyl group is not, it appears that the NH groups are bonded to other hydrogen bond acceptors in the materials - presumably the soft segment ether groups (12). A large amount of hydrogen bonding between the urethane and ether groups is suggestive of a one phase morphology with hard segments dispersed in a soft segment matrix. In contrast, the IR spectra of PTMO-38 indicates a majority of both the urethane and carbonyl groups are hydrogen bonded. This behavior is typical of a phase separated polyurethane where the hydrogen bonding occurs mainly in the hard segment domains (12).

Ion incorporation has a profound effect on the hydrogen bonding characteristics of the polyether polyurethanes. A comparison between the spectra of PTMO-20 and PTMO-20-10.3 reveals that upon ionization the carbonyl absorption changes from primarily free to primarily bonded. This would indicate aggregation of hard segments since the soft segments do not contain any electron acceptors. In addition, since in sample PTMO-20-10.3 70% of the urethane hydrogens are replaced (Table 1), the data suggest interactions between carbonyl groups and sodium atoms. Ionization also decreases the bonded nitrogen absorption as expected since 70% of the urethane hydrogens are replaced. The small peak at approximately 3575 cm^{-1} could be due to free NH groups but is more likely OH bonding resulting from a small amount of absorbed water.

Ionization of PTMO-38 to PTMO-38-6.5 produces different effects. In this case, ion incorporation is accompanied by a decrease in the bonded carbonyl fraction. Also, the NH peak is broadened, shifted to a slightly lower wavenumber, and its area is decreased. The change from bonded to free carbonyl groups would seem to indicate an unexpected decrease in the degree of phase separation. A similar phenomena has been observed previously for zwit-

terionomers and attributed to urethane groups bonding to the stronger proton accepting sulfonyl groups (2). This explanation is also suggested by a shift of the bonded NH peak to lower frequencies indicating participation in a stronger hydrogen bond. However, as discussed above this behavior was not observed for the PTMO-20 materials. PTMO-38 is an MDI/BD based polyurethane known to contain a microphase separated morphology in which ordered urethane domains possess a high degree of interurethane hydrogen bonding (13). Thus it is also possible that the change in carbonyl behavior is at least partially due to disruption of the ordered packing arrangement upon ionization. That is, ionization of the hard segments may impede formation of ordered structures by reducing the symmetry of the hard segment units and increasing steric hindrance. Disruption of packing is also suggested by the appearance of a free NH shoulder in the NH absorption peak of sample PTMO-38-6.5. The differences in the hydrogen bonding behavior of the two ionized samples are apparently a result of different domain structures resulting from the differences in hard segment length and ionic content.

Thermal Analysis

DSC curves are shown in Figures 2 and 3 for the PTMO-20 and PTMO-38 series materials respectively. Thermal transition data are summarized in Tables 2 and 3 respectively. For each material a compression molded sample (control) was heated at 20°C/min up to 230°C and then quench cooled and heated again. The results for the PTMO-20 series materials show a dramatic change in thermal behavior with increasing ionic content. The unionized PTMO-20 sample exhibited a sharp glass transition zone unaffected by quenching, characteristic of a one phase material. The glass transition of PTMO-20-0.8 is centered at a slightly lower temperature and the heat capacity change (ΔCp) is smaller (Table 2) indicating that some phase separation is beginning to occur. Further increasing of the ionic content to 4.5% results in a noticeably broader glass transition cen-

tered at a lower temperature with a smaller ΔC_p. All of these results can be attributed to the development of phase separation. More interesting however is the development of some ordering in the hard segment domains that leads to the distinct endotherm observed at 105-110°C. This ordering and phase separation closely parallels the change from mostly free to mostly bonded carbonyl groups in the IR spectra. Further, increases in ionic content (samples PTMO-20-10.3 and PTMO-20-12.1) continue to lower the soft segment glass transition temperature and narrow the transition zone indicating increasing phase separation. The decreased ΔC_p also observed with increasing ionization implies an increase in the degree of physical crosslinking which strains soft segment mobility. Increasing ionic content also improves hard s ~ent domain cohesion as indicated by the hard segment ordering endotherm moving .c igher temperatures.

The results of increasing ionic content on the PTMO-38 series materials are noticeably different as might be expected based on the infrared analysis. The unionized PTMO-38 exhibits thermal behavior characteristic of phase separated MDI/BD based polyurethanes. The three high temperature endotherms have been attibuted to various degrees of ordering in the hard segment domains (14). When PTMO-38 is quenched from high temperature a more phased mixed state relative to the initial state is 'frozen in' resulting in a higher soft phase glass transition temperature. After passing through the glass transition a large exothermic peak and two endotherms are observed. This is probably due to recrystallization of the hard segments which is followed by a disordering and melting endotherm (15,16).

Low degrees of ionization in PTMO-38 results in materials (PTMO-38-1.3, PTMO-38-3.3) with a higher soft segment glass transition indicating a decrease in the degree of phase separation. As suggested by the IR analysis this unusual behavior is probably due to disruption of hard segment ordering. The well defined endotherms observed for PTMO-38 are not present in PTMO-38-1.3 and

PTMO-38-3.3. Apparently ionization disrupts favorable hard segment packing arrangements causing more hard segments to be dispersed in the soft phase. Further ionization to 6.5% produces a material (PTMO-38-6.5) with the same soft segment glass transition temperature as the original material (PTMO-38); it appears that the effect of increasing segmental polarity difference is offsetting the effect of disrupting the hard segment ordering. Since a well defined high temperature endotherm is not observed it is unlikely that the increase in the degree of phase separation is a result of increasing ionization creating new favorable packing arrangements.

The existence of well defined hard segment endotherms in the phase separated PTMO-20 based materials is interesting because similar endotherms have not been reported previously for polyurethane ionomers. This is due to the fact that previously studied polyurethane ionomers were based on MDEA extended hard segments. MDEA is an asymmetric molecule and its incorporation in the hard segment tends to disrupt hard segment ordering. However, it is also interesting that similar distinct endotherms are not observed for the PTMO-38 based anionomers. This is likely a result of the longer hard segment length and broader hard segment length distribution of PTMO-38. The PTMO-20 based materials only contain one MDI unit long hard segments which should therefore pack easily. In contrast, the PTMO-38 materials probably contain a wide distribution of hard segment lengths (8,17).

Dynamic Mechanical Analysis

The results of dynamic mechanical experiments are displayed in Figures 4 and 5 for the PTMO-20 and PTMO-38 series materials respectively and parameters determined from the curves are summarized in Table 4. Figure 4 shows that the storage modulus of PTMO-20 does not exhibit a plateau region following the glass transition. This agrees with the DSC and IR results since it indicates that PTMO-20 is a one phase material. Upon ionization a plateau region develops and

the plateau modulus rises with increasing ionization level. This indicates increasing phase separation and an enhancement of the physical crosslinking and filler effects. The dramatic extension of the plateau region to higher temperature with increasing ionization is indicative of greatly enhanced hard segment domain cohesion. Both of these results are in agreement with the DSC data. Using the position of the E'' peak (β max, Table 4) as a measure of the position of the soft phase glass transition temperature reveals the trend noted previously of decreasing glass transition with increasing ionization attributed to increasing phase separation. Ionization also results in a small secondary maximum (β' max, Table 4) in the loss modulus curve indicating some disruptive process in the hard segment domains. This maximum moves to higher temperatures with increasing ionic content demonstrating improved domain cohesion.

The dynamic mechanical behavior of the PTMO-38 series materials is shown in Figure 5. Once again there is agreement with the DSC results. The position of the β max peak in the E'' curve can be seen to exhibit the same trend with ionic content as the glass transition temperature measured by DSC. A slight increase in the plateau modulus between 0 and 100°C in the PTMO-38-1.3 and PTMO-38-3.3 samples relative to PTMO-38 can be primarily attributed to an increase in the glass transition temperature which effectively shifts the E' curves to higher temperatures. Sample PTMO-38-6.5 however exhibits a marked modulus enhancement. This could be related to a change in morphology or hard segment domain structure but based on the DSC analysis is probably simply the result of regaining a high degree of phase separation coupled with enhanced domain cohesion due to the high ionic content. The high temperature transition (shoulder) (β'max, Table 4) in the E'' curve of the ionized samples is probably a hard segment glass transition that is not observed in the more ordered PTMO-38 control sample. Heating past this glass transition eliminates the dimensional stability provided by the hard

-10-

segment domains and causes as expected a sudden drop in the storage modulus that effectively limits the high temperature use of these materials.

Tensile Properties

Stress-strain curves are presented in Figures 6 and 7 for the PTMO-20 and PTMO-38 based materials respectively. Tensile properties are summarized in Table 5. The unionized PTMO-20 sample is too soft and weak to be tested at room temperature. Figure 6 and Table 5 show that the strength and extensibility of this material is remarkably improved even at low levels of ionic content. Based on the previous experiments, the increase in tensile properties upon ionization is attributed to the development of a two phase morphology. At high levels of ionization, the materials behave more like a plastic, exhibiting a high modulus and a low elongation at break.

The PTMO-38 control material exhibits the tensile properties of a good conventional elastomer. Initially ionization does not improve the modulus, a result that agrees with the dynamic mechanical data. Low degrees of ionization do give rise to higher stresses at break with correspondingly lower elongations. At higher ionic content (sample PTMO-38-6.5), a much higher modulus in accord with the dynamic mechanical data is observed. The tensile properties of sample PTMO-38-6.5 are roughly comparable with tensile properties of MDEA based zwitterionomers of similar chemistry and ionic content and are better than tensile properties reported for MDEA based anionomers (1,3).

Summary

Two series of polyether polyurethane anionomers have been synthesized and their properties investigated using DSC, IR, stress-strain and dynamic mechanical analysis. PTMO-20 exhibited a one phase morphology that upon ionization underwent phase separation. Further ionization improved the degree of phase separation and hard segment domain cohesion. Higher ionic content samples also

exhibited a distinct high temperature endotherm indicative of hard segment ordering. As a result of these morphological changes, increasing ionic content led to a greater dynamic modulus that was extended to much higher temperatures, and improved tensile properties.

In contrast, the PTMO-38 material demonstrated a two phase morphology and a high degree of hard segment ordering. Low levels of ionization disrupted this hard segment ordering thereby decreasing the degree of phase separation, but it did not appreciably affect the mechanical properties. As the ionic content was increased a high degree of phase separation was reattained resulting in a dramatic improvement in the mechanical properties. However, there was still no evidence of hard segment ordering. The lack of ordering in these materials was attributed to the broad hard segment length distribution of PTMO-38 in contrast to the monodisperse one unit long hard segments of PTMO-20 which should pack more readily.

ACKNOWLEDGEMENTS

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Table I

Sample	Composition MDI/BD/PTMO			Wt% Hard Segment	% of Urethane Hydrogens Replaced[a]	Wt% NaSO$_3$ Calculated[b]	Exp[c]
PTMO-20	1	0	1	20	-	0	-
PTMO-20-8	1	0	1	20	5	.8	.8
PTMO-20-4.5	1	0	1	20	29	4.5	4.5
PTMO-20-10.3	1	0	1	20	70	10.3	10.3
PTMO-20-12.1	1	0	1	20	85	12.1	12.1
PTMO-38	3	2	1	48	-	0	-
PTMO-38-1.3	3	2	1	48	4	1.3	-
PTMO-38-3.3	3	2	1	48	11	3.3	-
PTMO-38-6.5	3	2	1	48	22	6.5	-

[a] Calculated based on amount of Na and MDI added during synthesis.

[b] Calculated based on amount of Na and SO$_3$ added during synthesis.

[c] Calculated based on wt% Na measured by Galbraith Laboratories Inc. Values based on wt% S were slightly higher.

Table II

Differential Scanning Calorimetry Data

| Sample | Glass Transition | | | Tm(°C) |
	$T_g(°C)^A$	Breadth (°C)	$\Delta C_p \frac{mCal}{g°C}$	
PTMO-20-0(C)*	-55	16	144	-
PTMO-20-0(Q)*	-55	16	144	-
PTMO-20-8(C)	-57	17	129	-
PTMO-20-8(Q)	-57	17	129	-
PTMO-20-4.5(C)	-62	26	123	107
PTMO-20-4.5(Q)	-62	27	120	106
PTMO-20-10.3(C)	-68	22	117	146
PTMO-20-10.3(Q)	-65	24	105	153
PTMO-20-12.1(C)	-73	18	108	197
PTMO-20-12.1(Q)	-70	20	90	202

[A] Midpoint (1/2 ΔC_p)

* C = Control
  Q = Quench

Table III

Differential Scanning Calorimetry Data

| Sample | $NaSO_3$ | Glass Transition | | $\Delta C_p \dfrac{mCal}{g°C}$ |
		$Tg(°C)^A$	Breadth	
PTMO-38 (C)*	0	-44	34	99
(Q)*	0	-12	34	144
PTMO-38-1.3 (C)	1.3	-31	47	66
(Q)	1.3	-16	47	99
PTMO-38-3.3 (C)	3.3	-30	47	93
(Q)	3.3	-27	46	102
PTMO-38-6.5 (C)	6.5	-45	– 43	72
(Q)	6.5	-39	55	81

^{A} Midpoint $(1/2 \Delta C_p)$

* C = Control
Q = Quench

Table IV

Dynamic Mechanical Data

Sample	$\beta_{max}(°C)(Tg)$	$\beta'_{max}(°C)$	Plateau Zone (°C)		
			Onset	End	Width
PTMO-20	-35	-	-	-	-
PTMO-20-8	-47	-	-10	68	78
PTMO-20-4.5	-50	53	-16	75	91
PTMO-20-10.3	-54	81	-22	155	177
PTMO-20-12.1	-63	100	-26	180	206
PTMO-38	-32	-	0	109	109
PTMO-38-1.3	-21	96	8	87	69
PTMO-38-3.3	-20	95	21	84	63
PTMO-38-6.5	-32	100	-3	95	98

Table V

Stress Strain Properties

Sample	E_y(MPa)	σ_b(MPa)	ε_b(%)
PTMO-20	-	-	-
PTMO-20-2.6	0.014	-	300
PTMO-20-6.6	5.4	0.07	1250
PTMO-20-11.1	5.4	10.0	400
PTMO-20-13.2	84	14.0	30
PTMO-38	42	23.0	535
PTMO-38-1.3	49	27	660
PTMO-38-3.3	53	32	580
PTMO-38-6.5	110	27	375

URETHANE

ANIONOMER
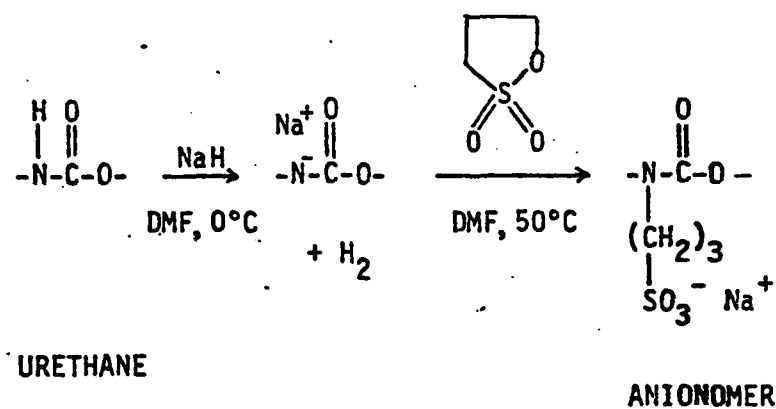
SCHEME 1

FIGURE CAPTIONS

Figure 1. Effect of ionization on the infrared spectra of PTMO-20 and PTMO-38

Figure 2. DSC thermograms for the PTMO-20 series of polyurethanes

Figure 3. DSC thermograms for the PTMO-38 series of polyurethanes

Figure 4. Effect of ionization on the dynamic mechanical properties of PTMO-20

Figure 5. Effect of ionization on the dynamic mechanical properties of PTMO-38

Figure 6. Stress-strain curves for the PTMO-20 series of polyurethanes

Figure 7. Stress-strain curves for the PTMO-38 series of polyurethanes

PTMO-20

PTMO-20-10.3

PTMO-38

PTMO-38-6.5

WAVE NUMBER (cm⁻¹)

3500 3000 1600 1400 1200 1000 800

FIG 1

PTMO-20 SERIES

PTMO-20

PTMO-20-.8

PTMO-20-4.5

PTMO-20-10.3

PTMO-20-12.1

—— CONTROL
- - - QUENCH

ENDO ΔQ →

PTMO-38 SERIES

PTMO-38

PTMO-38-1.3

PTMO-38-3.3

PTMO-38-6.5

CONTROL
QUENCH

ENDO $\Delta Q \longrightarrow$
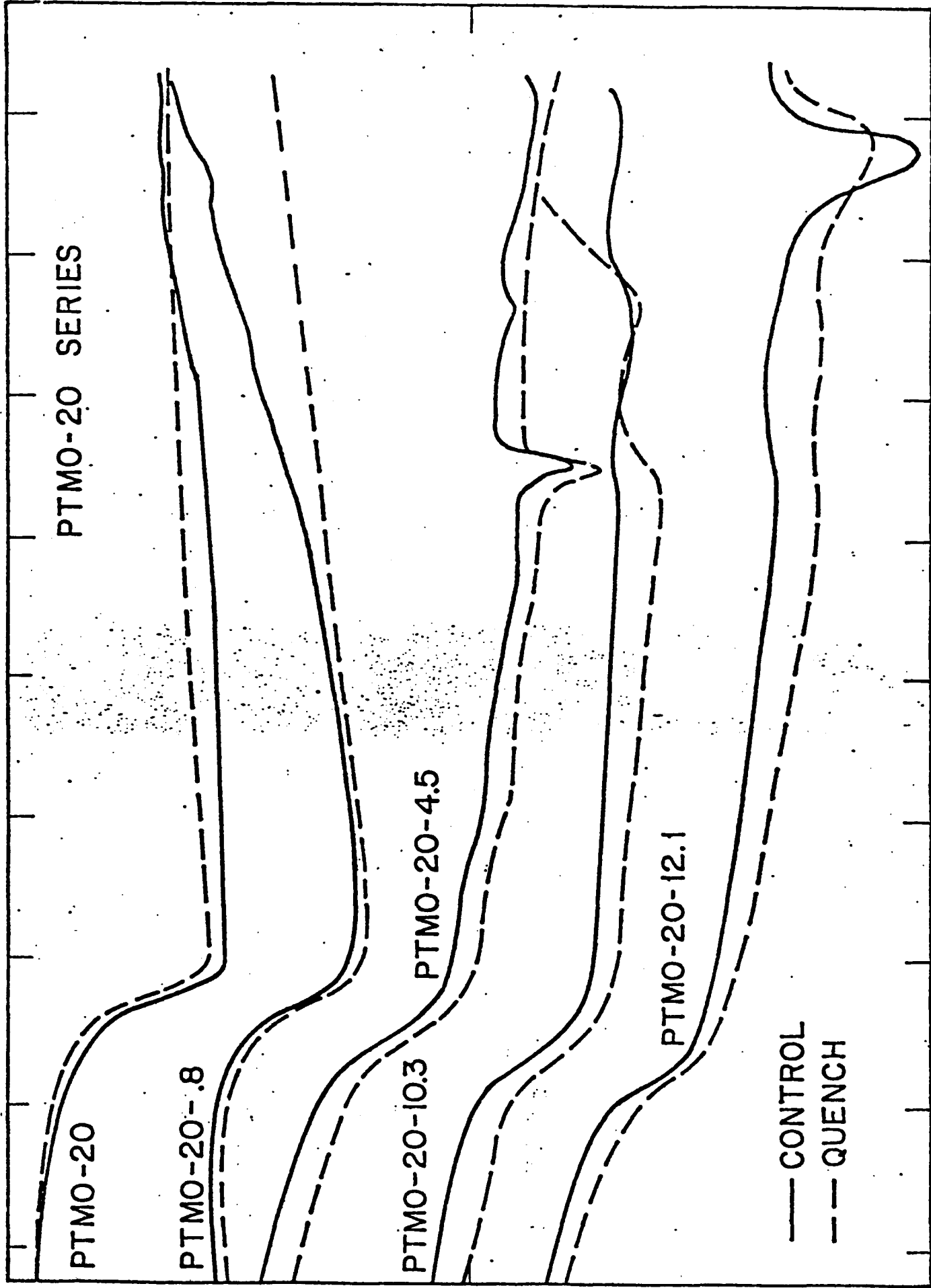
-120   -80   -40   0   40   80   120   160   200
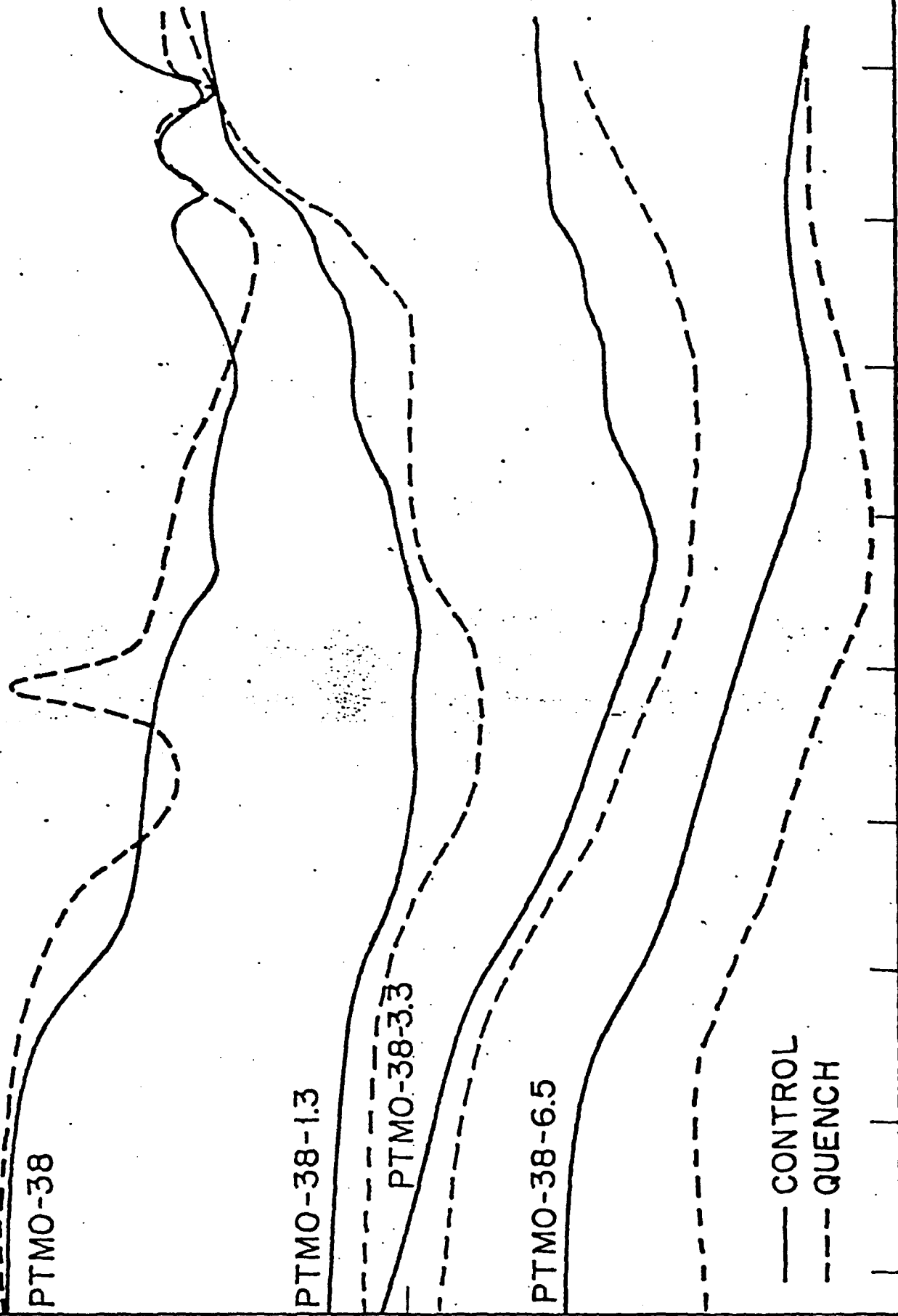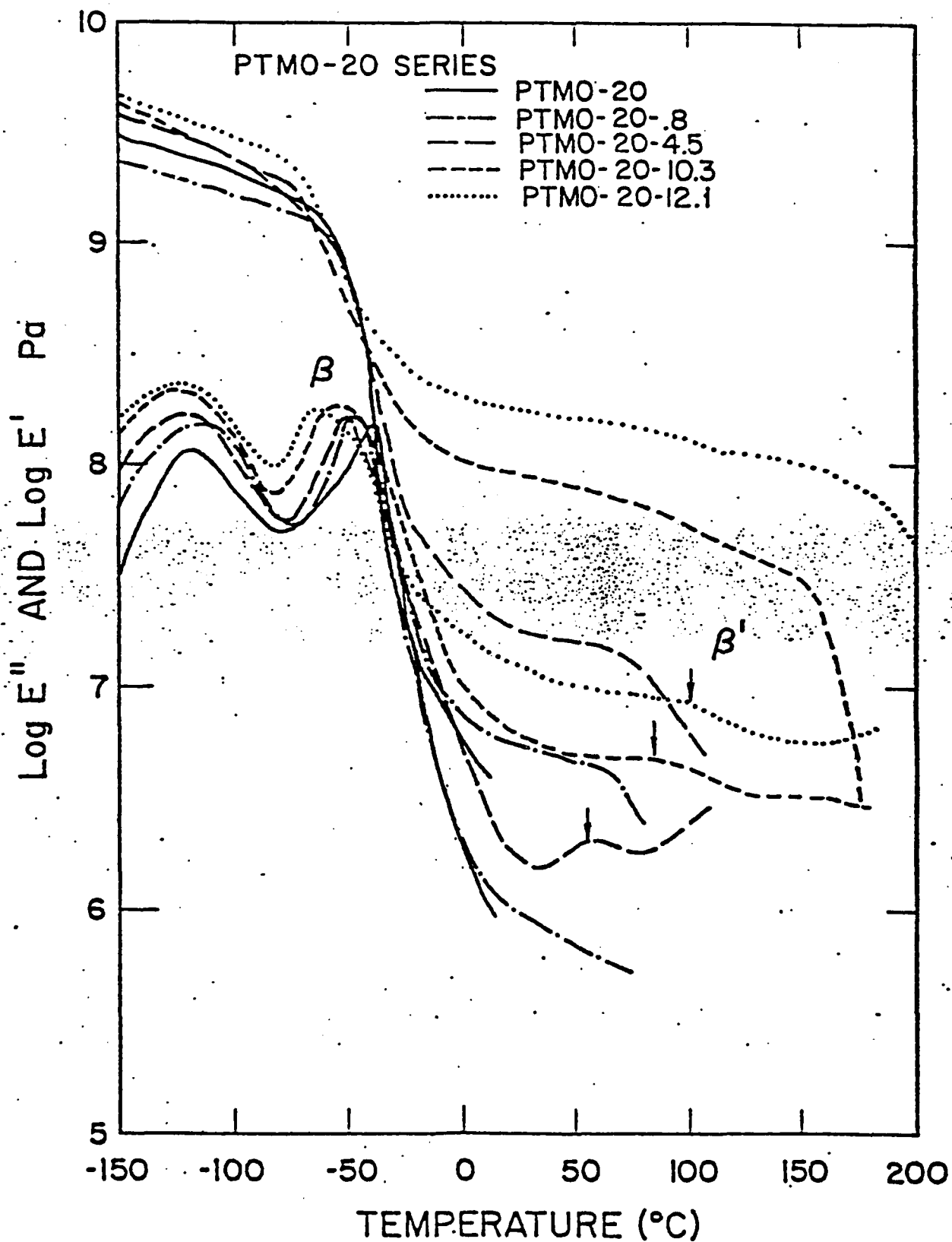
FIG 4
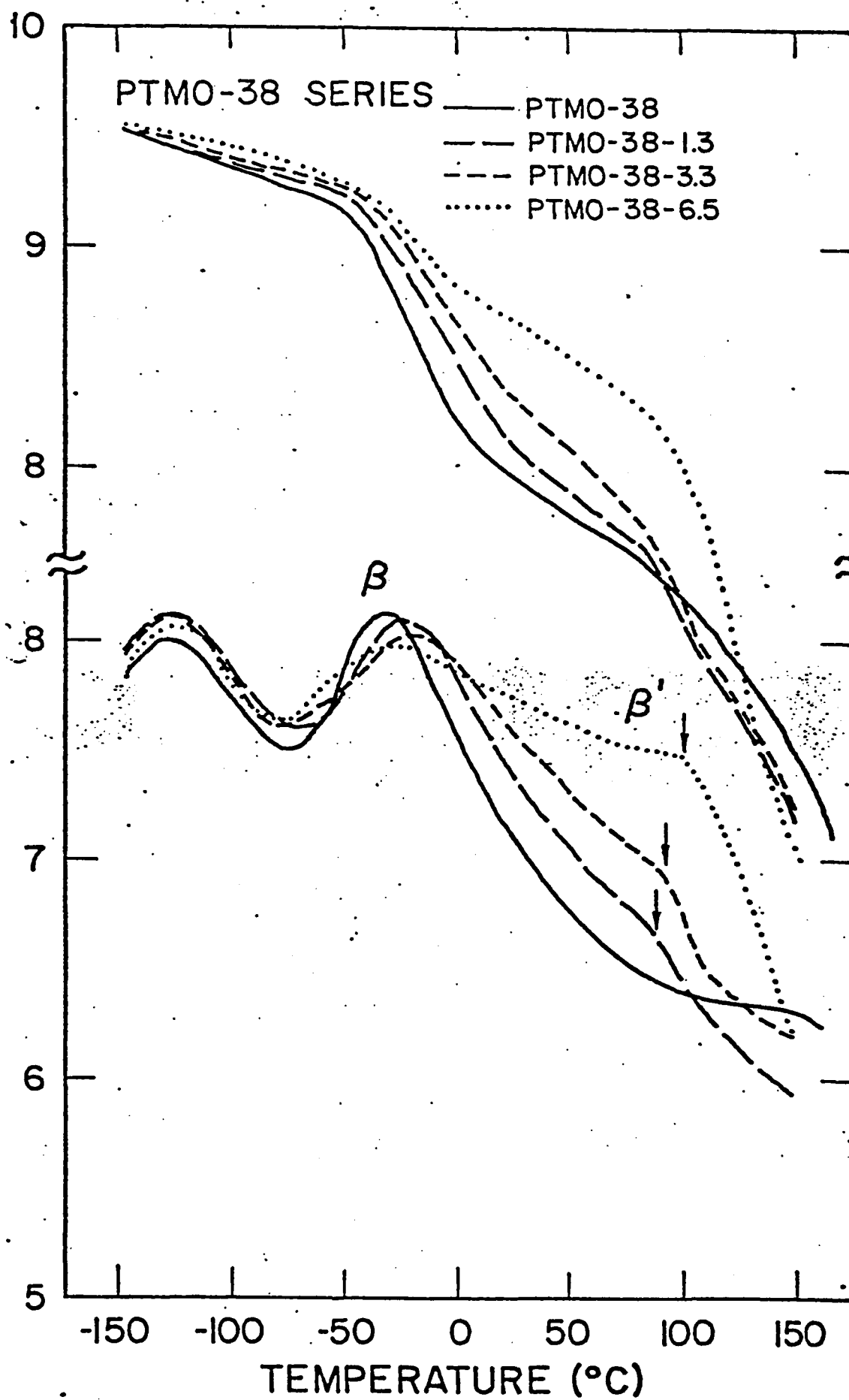
FIG 5

PTMO-2O SERIES

PTMO-2O-12.1

PTMO-2O-1O.3

PTMO-2O-4.5

PTMO-2O-.8

STRESS, MPa

15

10

5

0

100   500   1000   1500
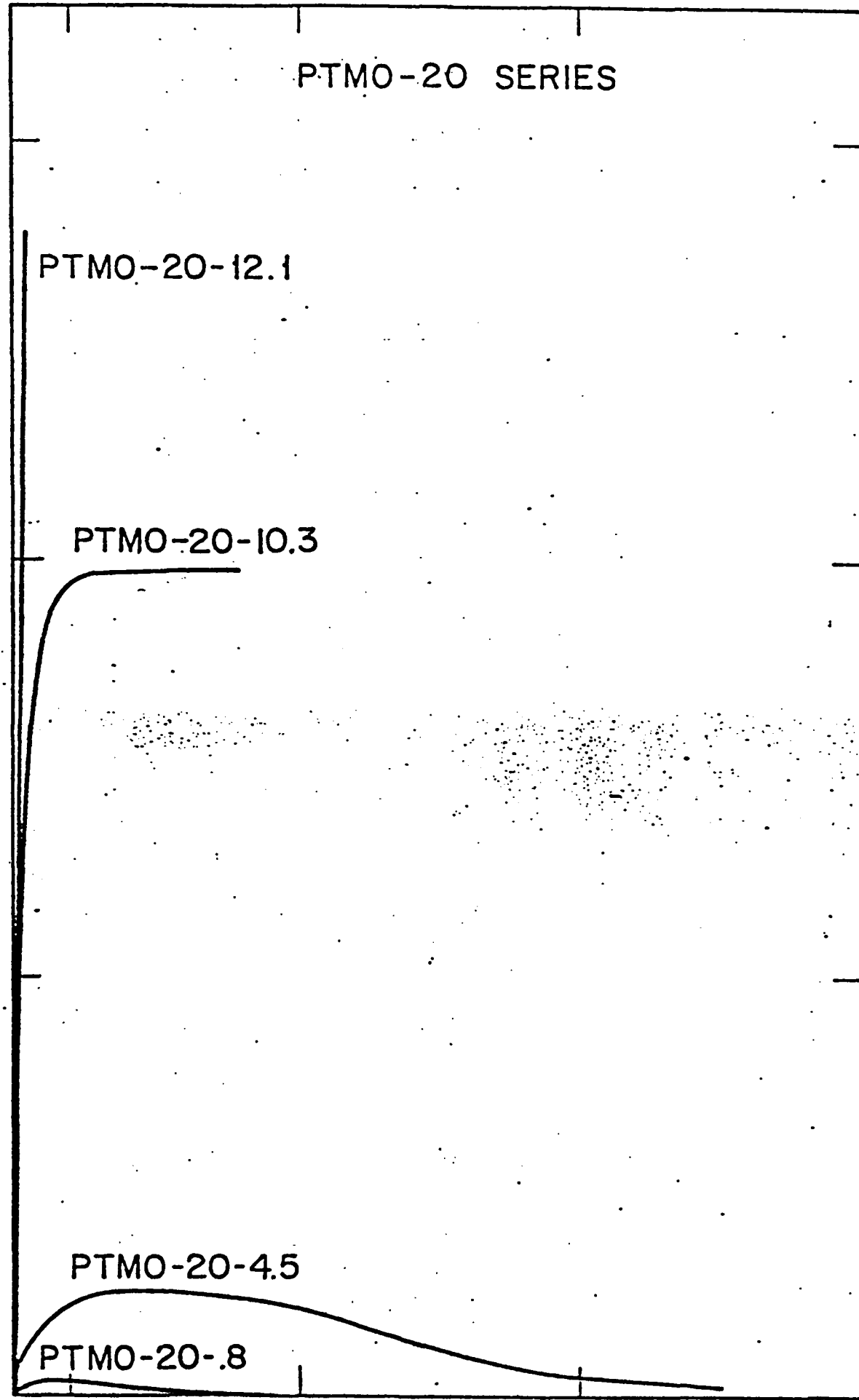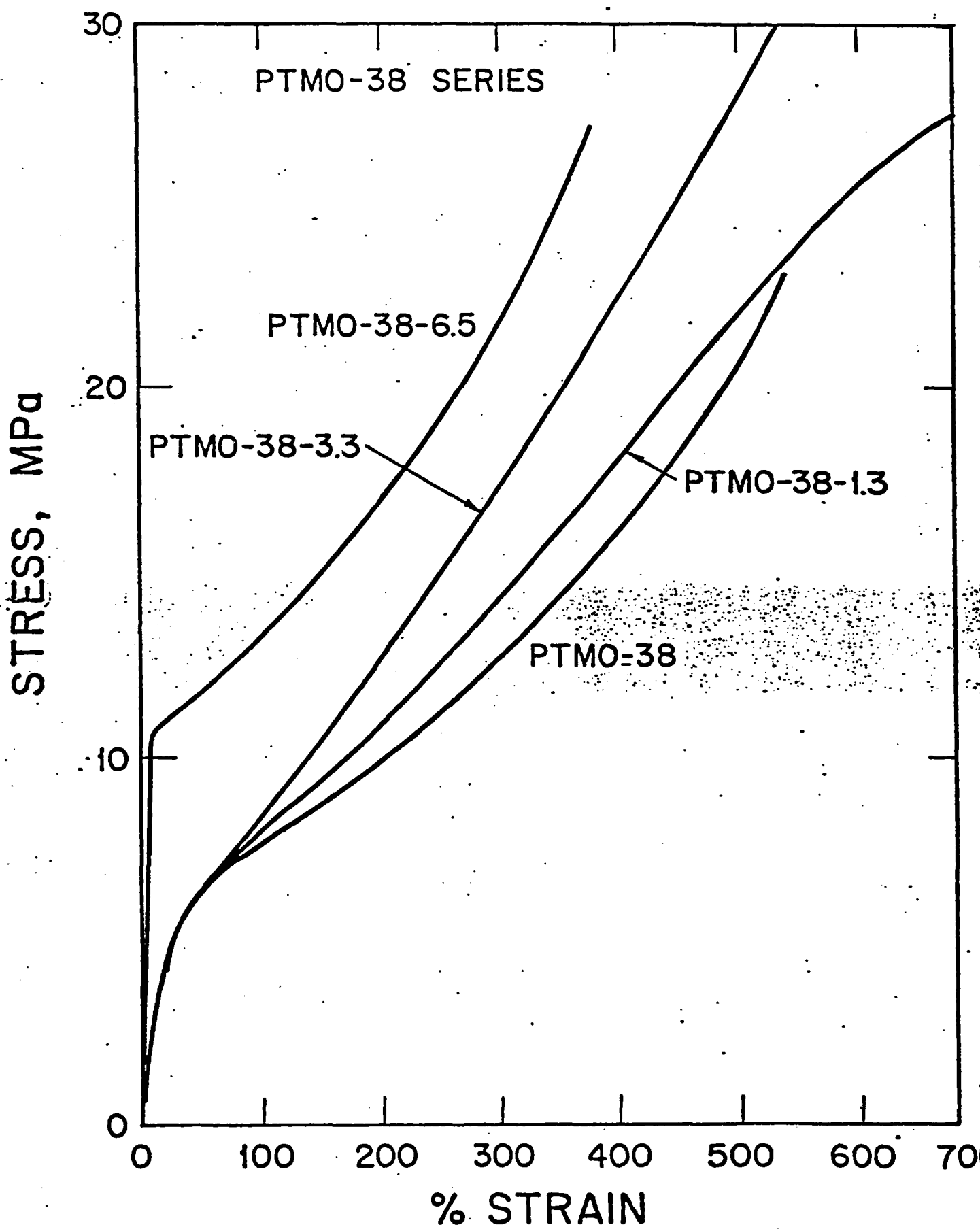
FIG 7

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